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Watercress Trials in Hampshire 1970-71

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Introduction

The origins and first year's results of this experiment were described in Agr. Memo. No 330[1]. The project was continued in 1970-71 on the same basis of collaboration between Mr M J Isaac, ADAS and the Meteorological Office. Meteorological recording began in early October and data on water temperatures are available from early November through to mid-March.

Meteorological Investigations

There have been three main areas of study:-

1. Changes in water temperature in the beds at different flow rates and at different points in the bed at a low rate of flow.

2. Variations in air temperature and humidity in a bed sheltered by a (moveable) polythene cover.

3. Reduction in light intensity due to the polythene cover and the condensate on the inner surface and the effect on this of forced ventilation.

Instrumentation

1. Twelve platinum resistance thermometers were positioned in beds 3 to 6 as in figure 1. to record water temperature variations. The thermometers were mounted vertically with their tips just clear of the bottom of the bed. Continuous records of temperature were obtained using two Kent Multi channel recorders at a chart speed of $3\frac{3}{4}$ inches per hour.

2. A mercury-in-steel thermograph was used to record dry and wet bulb temperatures under the polythene cover on bed 14. The bulbs were exposed in a small screen half way along the bed and about 2 feet above the crop.

3. Measurements of light intensity in the open and under the polythene cover were made on several occasions using a photo-electric cell calibrated in lumens $feet^{-2}$ (foot candles).

4. Observations of maximum, minimum, wet and dry-bulb temperatures and rainfall were made at 0900 GMT daily. In addition, a second mercury-in-steel thermograph gave a continuous record of air temperatures (wet and dry bulb) and run-of-wind at 2 metres was recorded continuously. A sunshine recorder was installed on November 18th.

Analysis

1(a) Water temperature changes at different flow rates

All flow rates are quoted in gallons $hour^{-1}$ yard $width^{-1}$. Flow rates to be studied were (nominally) 200, 400 and 600 but normal commercial practice

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of increasing the flow rate as the crop grew was followed and Table 1 shows the changes in flow rate for the four beds under investigation.

Table 1

Rates of flow (Gal. hr^{-1}. yd^{-1})

Date	Bed Number			
	3	4	5	6
2.10.70	36	36	36	36
13.10.70	184	184	36	36
17.10.70	184	184	184	184
29.10.70	184	384	384	184
21.12.70	184	384	552	184

Throughout the remainder of this report, results will be related to the nominal flow rates of 200, 400 and 600.

The exposure of the thermometers undergoes a progressive change as the cress grows and deeper, faster flowing water is introduced. Since the sensors were not moved during the experiment the temperatures recorded represent different environments at different stages of cress development. It is necessary to define three (arbitrary) "growth stages" as in figure 2:-

Stage 1 Shallow (up to about 1 inch) slow flowing (about 50 gal. hr^{-1} yd^{-1}) water in which the small seedlings are entirely contained. The thermometer is largely unprotected from direct sunshine and the sensing element may not be entirely immersed in the water/plant medium. Some temperatures will be too high due to direct radiation, some too low due to a partial wet bulb effect but nevertheless some parts of the cress plant will probably experience similar variations in temperature.

Stage 2 Deeper (about 2 to 3 inches) faster flowing (200 to 400 gal. hr^{-1} yd^{-1}) water with the plant canopy a little above the water surface. The sensor is completely immersed in the water and is shaded by the plants and at this stage there is probably a close correspondence between the measured water temperature and the environment temperature of the cress plant although some upper leaves will at times be much warmer by day and colder by night - even to the extent of frost damage to leaves only an inch or so above the surface of water at a temperature of several degrees above freezing.

Stage 3 Maximum water depth (3 to 4 inches) and final flow rates (up to 600 gal. hr^{-1} yd^{-1}). The thermometers and water surface are both completely shaded by the cress and there is an insulating volume of air/plant material between the water surface and the canopy. The major temperatures changes now take place in the crop canopy and the water temperature shows little reaction to the air temperature changes.

Because of the flow rate changes (see Table 1) complete data for all rates of flow at each growth stage are not available.

Good correlation is found between the drop in temperature from the well (constant temperature of 10.3°C) to the bottom of the bed and the difference between well temperatures and mean air temperature.

/Regression

Regression analysis of the available data gives the results in Table 2 and Figure 3.

Table 2

Estimation of outlet temperature at various flow rates

Flow Rate (gal hr^{-1} yd^{-1})	Growth Stage	Regression	Standard Error of Estimate (°C)	Correlation Coefficent
200 (Stale)	1	$D = 0.54(10.3 - \overline{T}) + 0.87$	0.77	0.83
" "	2	$D = 0.46(10.3 - \overline{T}) + 0.30$	0.95	0.85
200 (Fresh)	2	$D = 0.33(10.3 - \overline{T}) + 0.24$	0.55	0.87
400	1	$D = 0.26(10.3 - \overline{T}) + 0.72$	0.44	0.78
"	2	$D = 0.14(10.3 - \overline{T}) - 0.09$	0.39	0.80
"	3	$D = 0.08(10.3 - \overline{T}) - 0.05$	0.22	0.54
600	2/3	$D = 0.12(10.3 - \overline{T}) - 0.29$	0.24	0.88

Where D = 10.3 - mean outlet temperature (ie the mean of 24 hourly values of outlet temperature)

$\overline{T} = \frac{1}{2}$ (max + min) air temperatures.

The stale water has the same initial temperatures but flows through about 100 yards of commercial bed (at flow rates unrelated to the experiment) before being pumped into the experimental bed. This is probably the explanation of the higher standard error of estimate for the stale water temperatures while the high value of correlation coefficient reflects the longer period of time the water is influenced by air temperature.

Similar analysis of the 1969-70 data from the 10-day mean values in Appendix 1 of Agr. Memo. No 330 gives (see also Figure 3);-

Flow Rate	Regression	Standard Error of Estimate (°C)	Correlation Coefficient
80/120	$D = 0.40(10.3 - \overline{T}) + 0.38$	0.58	0.84
300	$D = 0.15(10.3 - \overline{T}) - 0.02$	0.21	0.85
500	$D = 0.09(10.3 - \overline{T}) + 0.22$	0.26	0.60

These results are all for growth stage 2 since the beds were planted, rather than sown, in 1969 and the last three values (growth stage 3) are disregarded.

If D is plotted against rate of flow for a given mean air temperature (eg 0°C) an approximately exponential increase in D with decreasing flow rate is indicated - see figure 4. The amount of cooling increases rapidly with flow rates of less than 300 gal. hr^{-1} yd^{-1} and the gain due to doubling the flow rate from 300 to 600 is only about 1°C.

This analysis was not repeated in detail for the inlet temperatures but an alternative method of estimating the inlet temperatures (with check results based on the above type of analysis) is given in Section 1(b) below.

1(b) Water temperature changes at various positions in the bed

The distribution of six thermometers in bed 6 (figure 1) was used to check the shape of the down- and cress-bed temperature profiles at a low flow rate (200 gal. hr^{-1} yd^{-1}). Theory suggest that the rate of

/change

change of temperature with distance down the bed should decrease with increasing distance from the inlet. Due to technical trouble with one recorder only a limited number of observation are available but these do support the theory.

To reduce these observations to the form of a single curve, rather than use the mean value of a broad spread of individual values, the ratio of the total well-to-outlet temperature fall to the value at intermediate positions has been plotted against down-bed distance - figure 5.

Roughly half the total temperature fall from well to outlet occurs before the water reaches the first thermometer position about 2 feet down the bed. This heat loss probably occurs during the "spill-over" from the covered ducts into the bed and may vary throughout the season as the concrete is subjected to different heating/cooling regimes and its heat store effect varies.

The greater cooling at the edges of the bed must be due to heat loss to the concrete since independent checks on water flow shows no retardation at the edges. The side to side differences between positions T_2 and T_4 reflect the shading effect of the side walls - T_2 is on the north side and is exposed to sunshine; T_4 on the south side is in almost permanent shadow.

Assuming that similar temperature profiles exist at other flow rates, a reasonable estimate of water temperature at any position in the bed may be made from air temperature data:

(a) Use the equations in table 2 to estimate the drop in temperature to the outlet.

(b) For a given down-bed distance, divide this value by the appropriate ordinate from the $(D_6 \div D_i)$ - axis in figure 5.

For example, if the mean air temperature is 0°C, a flow rate of 400 at growth stage 2 would give an average drop to outlet temperature of 1.35°C. The inlet temperature drop under these conditions would be $(1.35 \div 1.8) = 0.75$°C. Regression analysis for inlet temperature of the form used in section 1(a) gives:

$$D = 0.08\ (10.3 - \overline{T}) - 0.06$$

leading to an inlet temperature difference of 0.76°C.

It seems reasonable that the profiles in figure 5 could be applied to longer commercial beds assuming that the cooling beyond the first 60 feet is roughly linear and approximately equal to the cooling rate between T_5 and T_6. If the air temperature was such that the outlet water temperature fell by 5°C then the drop to position T_5 would be $(5 \div 1.08) = 4.6$°C, ie a rate of change of 0.4°C per 20 feet or roughly 0.5°C for every 10 yards to extrapolate the results to longer beds.

2. Air temperature and humidity under polythene covers

Bed 14 was covered from January 1st to 28th with forced ventilation during the day. The ventilation was used in an attempt to reduce the amount of condensate on the inner surface of the polythene and also served to depress the daytime maximum temperatures under the cover.

Air flow into the covered bed under ventilation was about 8 kt giving roughly 100 air changes per hour or about 7 $ft^3\ min^{-1}\ ft^{-2}$ of bed area.

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Good negative correlation was found between outside air temperature (T) and the increase in air temperature due to covering.

Regressions for P (inside minus outside air temperatures) are:

Time (GMT)	Regression	Standard Error of Estimate (°C)	Correlation Coefficient
2100 to 0600	P = 5.38 - 0.32T	1.02	- 0.95
0900 & 1800	P = 5.14 - 0.27T	1.11	- 0.92
1200 & 1500	P = 3.54 - 0.14T	1.53	- 0.68

Since the 1200 and 1500 values were most affected by ventilation (not all 0900 and 1800 values were under ventilation) the lesser protection as well as increased variability are to be expected - see also figure 6.

Little effect on relative humidity was found with the humidity falling below 100% on only one or two occasions around the time of maximum temperature. As in 1969-70 (without ventilation) it is unlikely that the humidity ever fell below about 95% under the covers. However, it is likely that ventilation would have a greater effect on the humidity later in the spring when the air being drawn through the cover would be warmer and drier.

3. Light intensity under polythene covers

The results here must be regarded as approximate because of a number of factors limiting the reliability of the observations:

(a) A photo-electric cell was used, not an illuminometer.
(b) The cell was not cosine corrected.
(c) Only one instrument was available so that variations in light value with time between inside and outside readings are only partly eliminated by averaging a series of readings.
(d) At high light intensities a home made filter had to be used to reduce the values to the scale range. The reduction factor of this filter had to be determined experimentally and is only approximate. In addition, the filter might well add to the errors introduced by (b) above.
(e) Only a limited number of observations could be made.

Nevertheless, the available data were consistent enough to warrant inclusion in this report pending more rigorous investigation of light levels.

The effect of the polythene cover plus the condensate appears to be a reduction of light intensity of about 25% in sunny and about 30% in cloudy weather.

It was not possible to measure any significant change due to ventilation but, since subjective visual observation seemed to show a decrease in the amount of condensate after ventilation, two conclusions are possible:

(a) The improvement due to ventilation was of the same order as the probable error in readings, or
(b) The reduction in light due to the additional effect of the condensate is small in relation to the effect of the polythene alone.

/Conclusions

Conclusions

1. Temperature fall from the well to the outlet is approximately 1°C at 600, 1½°C at 400 and 3°C at 200 gal. hr^{-1} yd^{-1} when the mean air temperature is 10°C lower than well temperature, ie mean air temperature of about 0°C. At other air temperatures the water temperature change is pro rata and (at least during the winter months) almost half of the heat loss occurs before the water reaches the cress in the beds.

2. Heat loss increases rapidly at flow rates below about 300 and the gain by increasing flow rate from 300 to 600 is only about 1°C suggesting that 400 gal. hr^{-1} yd^{-1} is probably the optimum flow rate as far as protection from low temperatures and economy in water is concerned.

3. The inter-relationship between water temperature and the environment temperature of the cress varies throughout the growth of the crop. The protective effect of the warm water is greatest at the mid period of the cress crowth. During early stages temperature fluctuations in both water and plant are greater and by the time the crop is ready for harvesting it is probable that the crop is protecting the water from air temperature effects rather than vice versa.

4. Covering with polythene protects the crop against low temperatures - by about 8°C at an outside air temperature of -10°C but the protection decreases by about 3°C per 10°C rise in air temperature.

5. By day, with the fan in operation, the protection would be about 5°C at an outside temperature of -10°C decreasing by about 1½°C for each 10°C rise in air temperature.

6. Under the cover, relative humidity is almost continuously 100%, falling below this value by up to about 5% only around time of maximum temperature when the ventilating air is warm and dry.

7. Loss of light due to the cover is about 25% in sunny and about 30% in cloudy weather. Ventilation appears (visually) to reduce the amount of condensate but no measureable effect has so far been found.

Any comments on this paper should be sent to the author.

Reference

1. Hurst G W and Cochrane J — Watercress trials in Hampshire, 1969-70. Agr. Memo. No 330.

Meteorological Office
Bracknell
Berkshire

June 1971

G. 13241/SS/6/71/120

Distribution of thermometers in cress beds

° Thermometer position (approximately to scale)

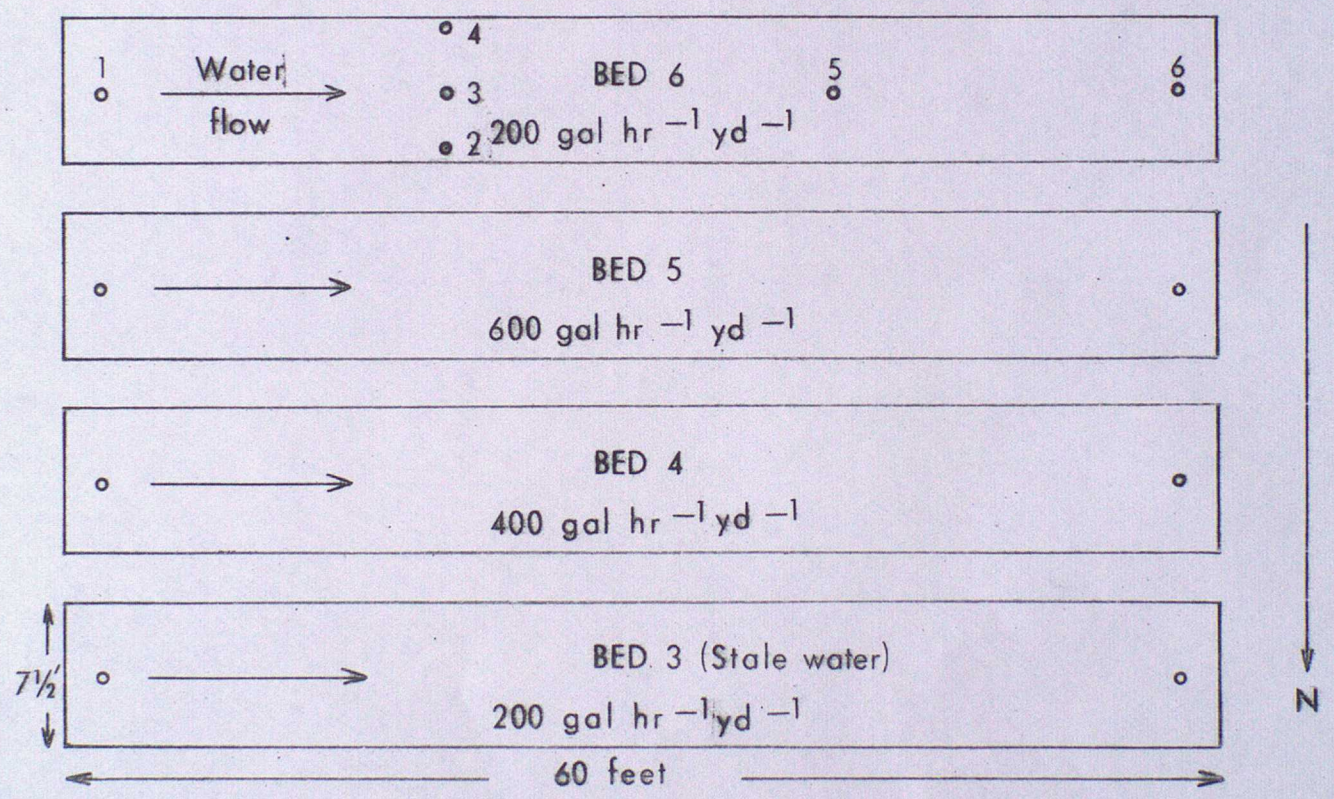

Figure 1

Changes in thermometer exposure due to cress growth
(not to scale)

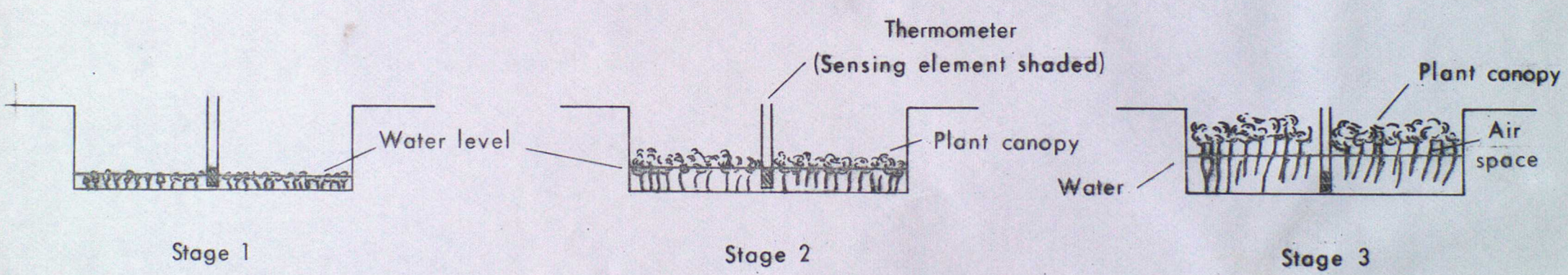

Figure 2

Outlet temperature according to air temperature and flow rate

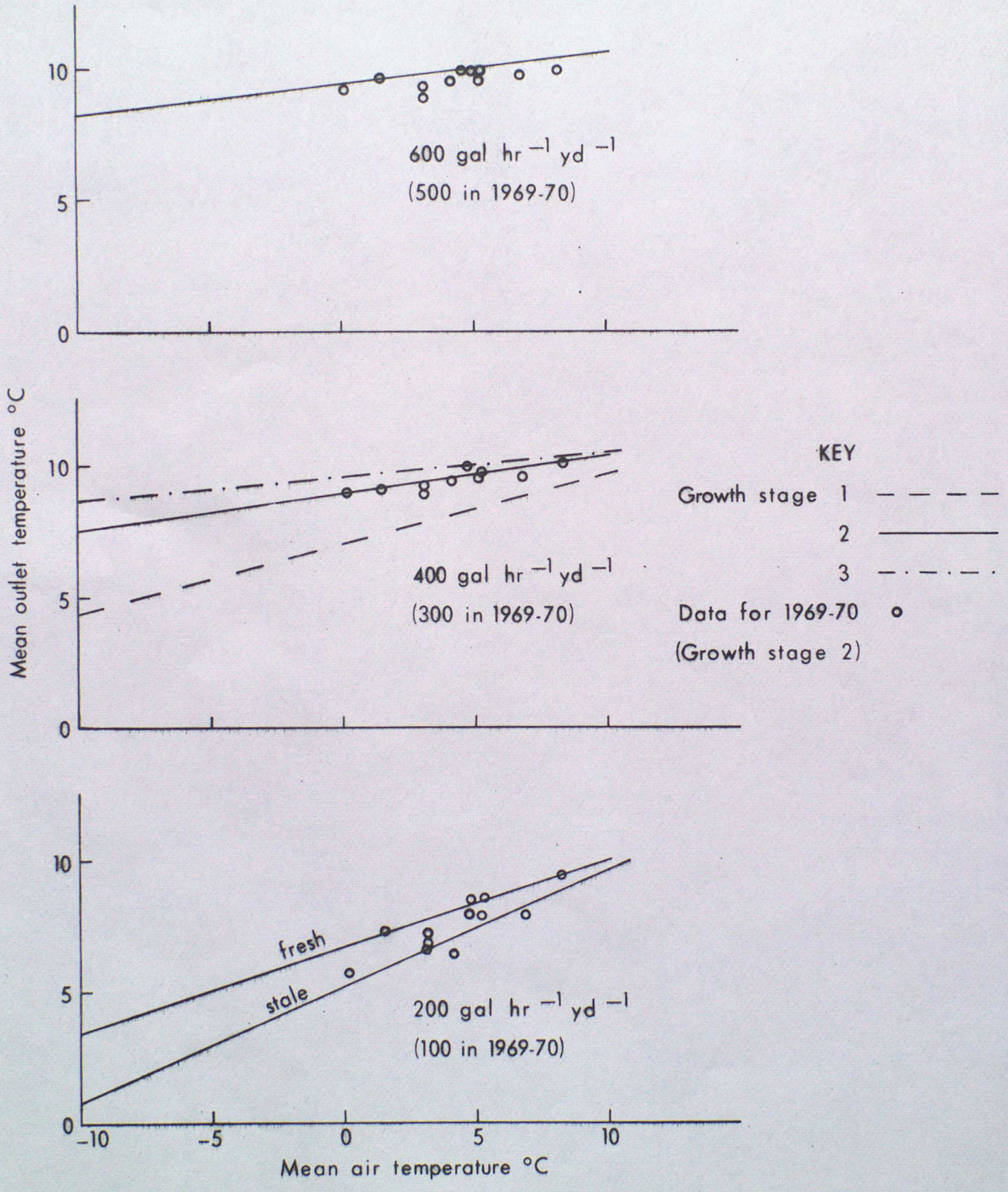

Figure 3

Temperature drop to outlet according to flow rate

(mean air temperature = 0°C)

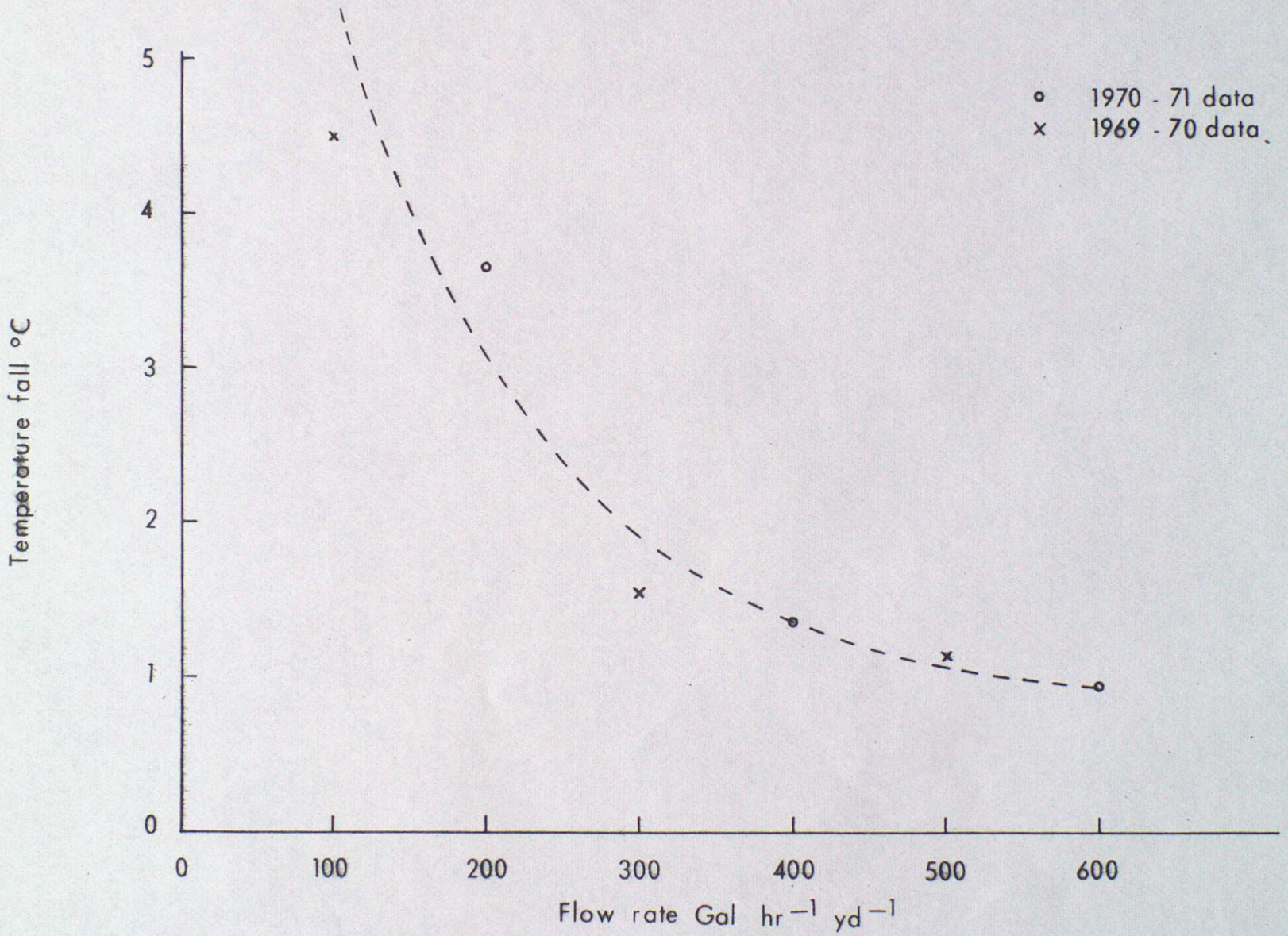

Figure 4

Temperature profiles in BED 6

D_i = Temperature fall to position T_i ie $(10{\cdot}3 - T_i)$ °C

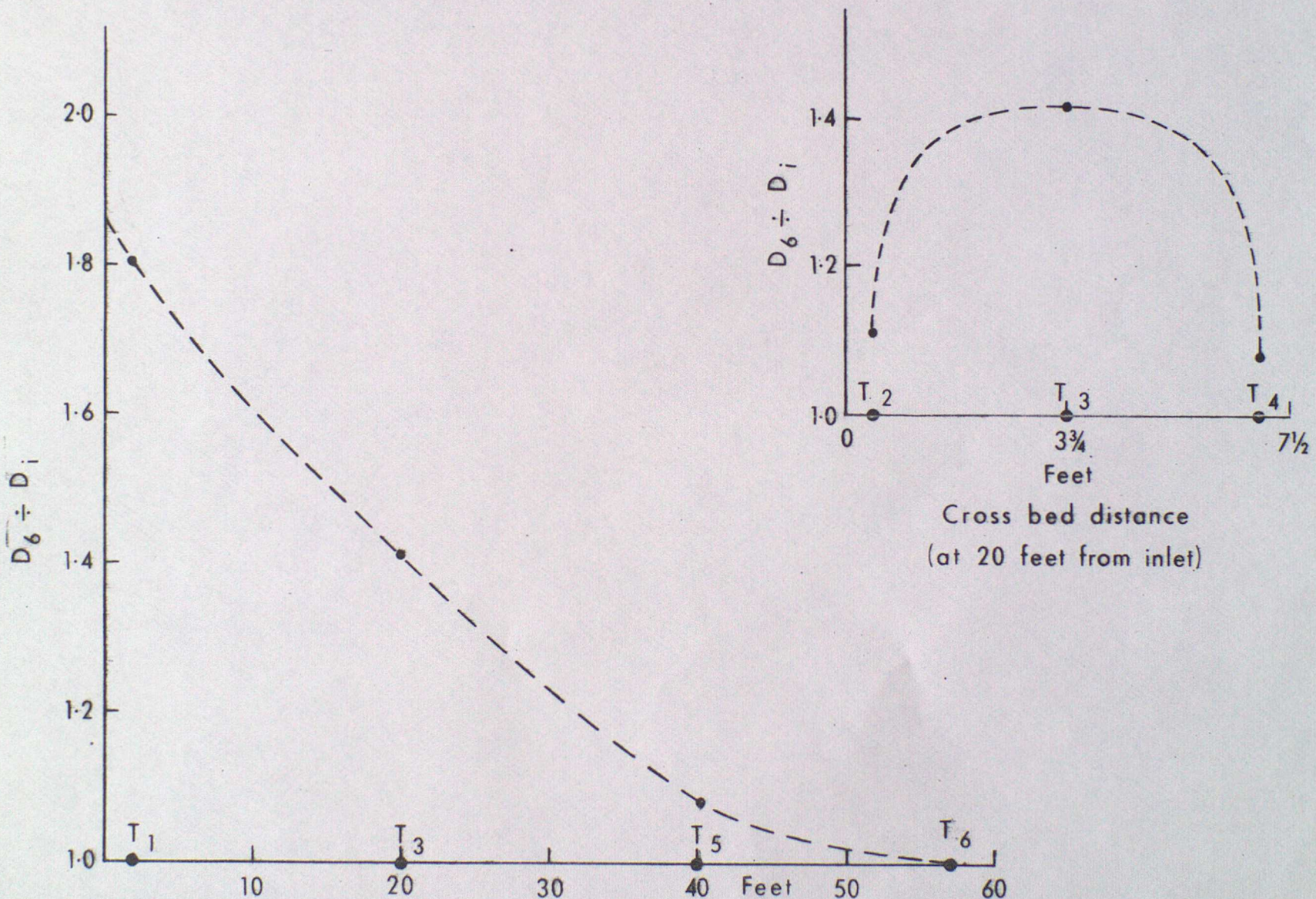

Figure 5

Protective effect of polythene cover

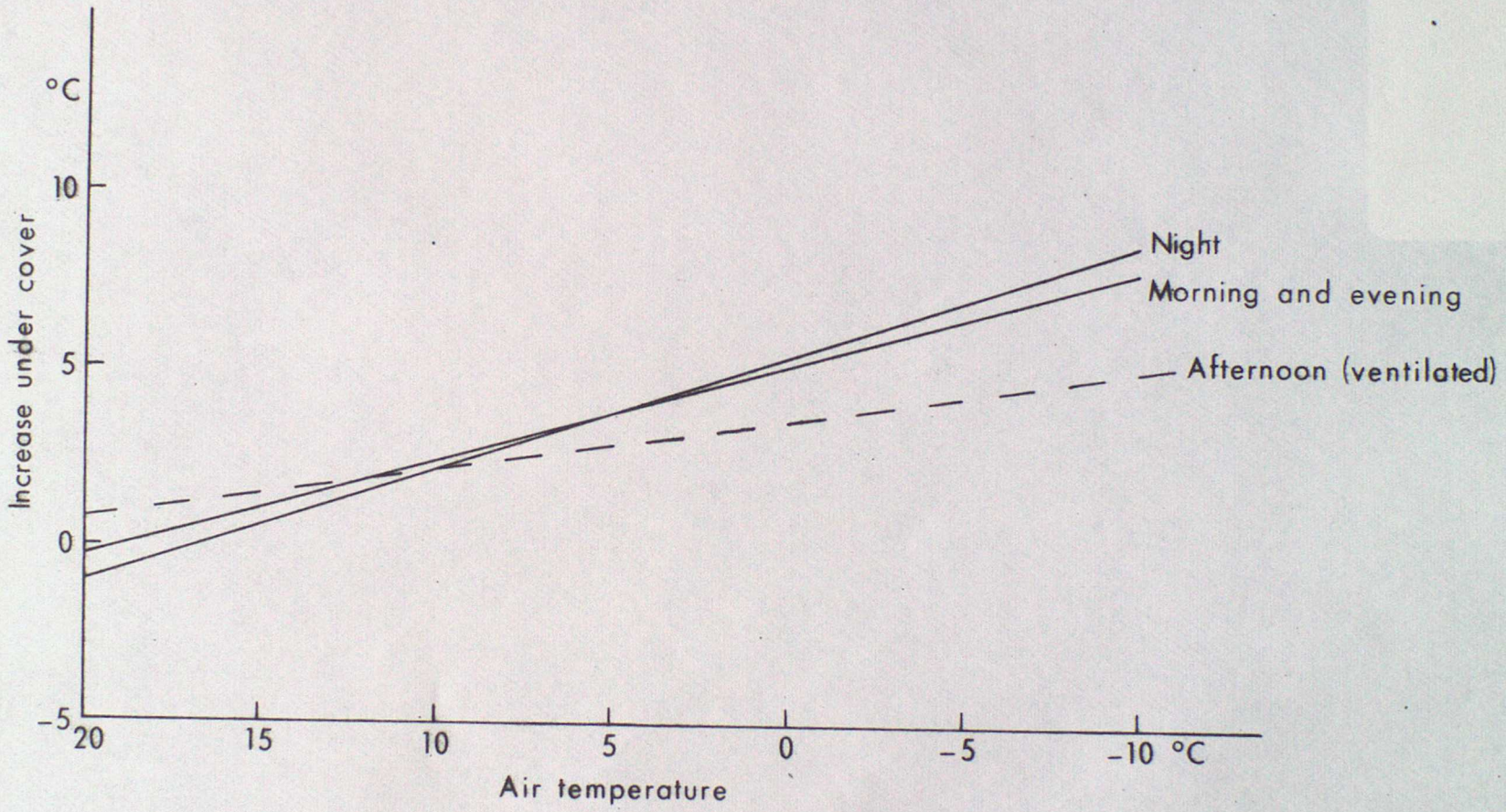

Figure 6